TECHNICAL EVALUATION REPORT:

HUMAN DIMENSIONS IN EMBEDDED VIRTUAL SIMULATION

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ABSTRACT

The North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) organized and conducted a workshop on human factors and performance issues related to embedded virtual simulation (EVS). The workshop was held on 20 – 22 October 20, 2009 at the University of Central Florida – Institute for Simulation and Training (UCF – IST) in Orlando, Florida. The purpose was to address human effectiveness issues related to application of EVS to the military domain. Papers were presented describing the current state of EVS technology. The conference participants generally agreed that technological and conceptual advances have led to the increased utility and effectiveness of EVS. At the same time, participants also noted that the technology has not been generally accepted by system and training developers. Reasons for the resistance to adopt EVS were identified, and a possible way forward was discussed.

1.0 INTRODUCTION

The North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) organized and conducted a workshop on human factors and performance issues related to embedded virtual simulation (EVS). The workshop was held on 20 – 22 October 20, 2009 at the University of Central Florida – Institute for Simulation and Training (UCF – IST) in Orlando, Florida.

1.1 Background

In its "Call for Papers," the NATO RTO identified the need for units to deploy with little or no notice and to adapt to evolving situations. This places units in locations where they do not have the facilities and infrastructure needed to train for, optimally plan, and rehearse complex missions. The use of EVS is seen as an essential tool to provide more effective deployed training. EVS is a concept that tightly integrates training and mission functionality into operational equipment. Recent advances in training concepts, intelligent agent technologies, computers, communication, and display technologies offer new opportunities for embedded training and mission preparation/rehearsal capabilities in a highly mobile military.

Although embedded virtual simulation is a known concept with many advantages, it has been rarely implemented in air and land platforms. The most challenging applications are deployed settings that provide little support to users in the way of instructional staff and/or infrastructure. To meet this challenge, embedded simulation will have to include a range of capabilities, e.g., an intelligent tutor, beyond those of existing simulation centres and simulators. Integrating Virtual Reality (VR), Augmented Reality (AR), and intelligent agent technologies in novel ways can significantly enlarge the area of application and introduce new

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The North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) organized and conducted a workshop on human factors and performance issues related to embedded virtual simulation (EVS). The workshop was held on 20 22 October 20, 2009 at the University of Central Florida Institute for Simulation and Training (UCF IST) in Orlando, Florida. The purpose was to address human effectiveness issues related to application of EVS to the military domain. Papers were presented describing the current state of EVS technology. The conference participants generally agreed that technological and conceptual advances have led to the increased utility and effectiveness of EVS. At the same time, participants also noted that the technology has not been generally accepted by system and training developers. Reasons for the resistance to adopt EVS were identified, and a possible way forward was discussed.

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capabilities that would enhance the systems' effectiveness. By utilizing network-enabled capabilities, it is possible to provide team, collective, joint, and coalition training and mission preparation/rehearsal on a wide variety of military skills, including warfighting, peace keeping and maintenance.

The military needs to understand the risks and benefits of embedded virtual simulation. It is important to carefully consider the science that can produce new embedded virtual simulation strategies and technologies. It is also important to understand how individual performance is changed by the use of embedded virtual simulation.

Based on this need, NATO RTO issued a call for papers to be presented and discussed at the workshop. In addition to the papers, the workshop committee members conducted a series of mind mapping exercises designed to brainstorm concepts related to EVS: requirements identification, training management, interface technology, and learning. A detailed agenda of workshop papers and activities is provided in the Appendix.

1.2 Workshop Goals and Objectives

In their introductory presentations to the workshop, Dr. Robert Sottilare (USA) and Dr. Thomas Alexander (DEU) and set the workshop goals and objectives. Dr. Alexander described the workshop's primary goal was "...to address human effectiveness issues across conceptual, functional and technological levels when using embedded virtual simulation in the military domain." Dr. Robert Sottilare (USA) identified the specific workshop objectives as follows:

- Military requirements for embedded simulation including policy and user requirements
- Operational constraints of embedded simulation
- Training and mission support requirements including intelligent tutoring, training management, performance measurement and feedback (e.g., after-action review in embedded simulation)
- Human-Technology Interfaces
- Application of intelligent agents
- Current and future directions for virtual simulation in operational platforms

2.0 KEYNOTE ADDRESSES

Following the introductory presentations, four invited speakers were asked to describe the current state of the art in EVS with examples from differing applications. The first of the keynote addresses was presented by Dr. Lochlan Magee (CAN), who described a number of applications to NATO militaries that illustrate recent progress in EVS technologies. Nevertheless, embedded training continues to pose significant problems for general application to military problems. The challenges he posed to the workshop were to identify gaps and to find potential solutions that will allow effective implementation of embedded virtual simulation.

Lt. Col. Gerbe G. Verhaaf of the Royal Netherlands Air Force Command discussed EVS technology from the user's perspective. He maintained that the requirement to fight asymmetric threats while deployed in a multinational coalition demands a training method that promotes high levels of proficiency but is less dependent on traditional instrumented ranges. As an example of such an advanced method, he described test versions of the F-16 MLU ("Orange Jumper"). This demonstration aircraft employed an EVS systems that allow training on the entire live and kill chain. This test bed serves as a prototype for the F-35 Joint Strike Fighter, for which embedded training is a design requirement.

Dr. Dirk Schmidt (DEU) of Krauss-Maffei Wegmann reviewed EVS from the research perspective. He presented his company's research into EVS technology for the Infantry Fighting Vehicle (IFV) Puma. His research findings indicated that embedded training systems can be successfully incorporated in ground combat vehicles. However, he noted that, for embedded training on a single vehicle, the vehicle commander needs to be trained as instructor and needs support by a Learning Management System (LMS). Dr. Schmidt also argued that, in addition to crew training, an EVS potentially provides a technological basis for mission rehearsal and decision support during missions.

Mr. James A. Shiflett (USA) of Science Applications International Corporation (SAIC) discussed EVS from a developer's perspective. His example was the Future Combat System (FCS), which was recently significantly restructured and no longer includes the development of manned ground vehicles. In its original concept, the FCS vehicle development program included embedded training as a key performance parameter (KPP) in system development. (KPPs are those system attributes considered most critical or essential for an effective military capability.) The FCS experience demonstrated that embedded training is a technically feasible and mature application to any ground vehicle. Cost estimates for building embedded training into FCS was about 3% of total system costs. Despite the redirection of FCS, embedded training remains a KPP for any new Army combat vehicle. Mr. Shiflett further argued that embedded training can be incorporated into existing systems if they are linked by a system-of-systems common operating environment (SOS COE) architecture and provide appropriate warrior-machine interfaces (WMIs).

3.0 SESSION 1: POLICY AND USER REQUIREMENTS FOR EMBEDDED TRAINING

Session 1 was led by Dr. Stephen Goldberg (USA) of the US Army Research Institute (ARI). This session identified and defined policy and user requirements for EVS technology through the examination of lessons learned from specific embedded training applications. By way of introduction, he reminded the workshop that policy toward embedded training dates back to 1987 when GEN Max Thurman, commander of TRADOC, wrote an instruction that embedded training was considered the first option for any newly acquired operational system. Although the policy was clear, it lacked appropriate enforcement provisions and was, for the most part, effectively ignored.

3.1 Presentations in Session 1

Brian Crabb, Jennifer Phillips, and William Ross asserted that the future Network Centric Environment (NCE) adds substantial lethality and effectiveness to ground units. At the same time, such increases in technical capability also add to the cognitive complexity of unit leader tasks and skills. Crabb et al. used the Dreyfus and Dreyfus (1986) model of expert development to describe how future leaders could acquire the necessary levels of competence required by the NCE. Such models typically specify that expertise is dependent on long periods (> 10 years) of deliberate practice. They proposed that embedded training technology could possibly break the 10-year rule by providing high levels of repetitive practice with automated guidance on a wide variety of conditions.

Bills, Flachsbart, Olson, and Kern discussed applications of embedded training in the F-35 (Lightning II), previously referred to as the Joint Strike Fighter. The training system is in this aircraft is fully embedded in the aircraft's integrated core processer (ICP), but partitioned into two components. One component is the virtual training (VT) system, which represents an extension of the system developed by Royal Netherlands Air Force for the F-16. The VT system enhances the training environment by overlaying constructive simulation

on the real world. The other component is the P5 Combat Training System that is integrated with the air combat manoeuvring instrumentation (ACMI) to provide on-board “rangeless” live combat training capability. Cost models of the F-35 program have projected cost-avoidance savings of nearly $3B USD over the full life cycle of the aircraft.

3.2 Mind Mapping Exercise for Session 1

The first mind mapping exercise was facilitated by Drs. Goldberg and Magee and sought to identify EVS requirements. The following describes the three specific questions asked, and some of the answers provided through the exercise:

3.2.1 What potential operational systems are good candidates for application of EVS?

The breakout groups provided examples of EVSs for a variety of operational systems. However, some examples had more challenges than others. For instance, C4ISR systems have computation power that could be used to realistically stimulate/simulate EVS targets. On the other hand, EVS systems on fast moving aircraft pose challenges in space requirements and simulation fidelity.

3.2.2 What are the human factors challenges for training and performance?

The blending of live and virtual simulation poses fidelity as well as safety issues. The primary pedagogical challenge is how to incorporate secondary roles (e.g., battle master, scenario generators, and role players) in a constrained operational environment.

3.2.3 What are the limitations of applying EVS, particularly those that have hampered implementation of the technology?

Concerns include space requirements, wear-and-tear on operational equipment, interference with operational equipment/effectiveness, and limited realism (particularly for close-in targets).

4.0 SPECIAL SESSION: STRESS AND SUICIDAL BEHAVIOR

One of the hallmarks of embedded training is that it is designed to be used in the deployed environment. In this special session, Pregelj pointed out that this environment has considerable negative emotional or behavioural consequences that could be associated with higher suicide risk. Research conducted in Slovenia on psychiatric populations indicated that patients with stress-related disorders expressed suicidal thoughts and attempted suicide more often than patients with non-stress-related problems. Comparisons with suicide victims having no previous histories of aggressive behaviours, victims with aggressive pasts were more likely to have more negative life events connected with private life in a month before suicide, to have attempted suicide more often, and to be successful in first suicide attempts. Preglj also presented possible physiological mechanisms for the link between stress and suicide that involved dysfunctions of the serotoninergic neurotransmitter system.

5.0 SESSION 2: HUMAN EFFECTIVENESS AND EMBEDDED TRAINING ENVIRONMENTS

Session 2 was facilitated by Dr. Dee Andrews (USA) with the US Air Force Research Laboratory (AFRL) and by Dr. Jan Roessingh (NED) with the Dutch National Aerospace Laboratory. Topics included the management of embedded training and distributed modes for embedded training.

5.1 Presentations in Session 2

Roessingh and Verhaaf explored the training effectiveness of embedded training in a multi-fighter environment. They cited research showing gains of 30% in effectiveness at the same cost by using embedded training in fighter aircraft. They also considered more qualitative benefits. For instance, they explored how embedded training relates to user needs and how embedded training could best contribute to the fulfilment of the training objectives for fighter pilots. They also provided a qualitative identification of the training effectiveness of embedded training when compared with “legacy” live training exercises or tactical training on simulators. Finally, the integration of embedded training with other forms or live, virtual, and constructive training was examined.

Cannon-Bowers reviewed the application of embedded training for high performance teams. The prototypical decision environment for her discussion was the AEGIS Combat System, which involves highly complex team interactions under time pressure. Her experience with such systems indicated that there are two essential questions: (1) How do experts perform their tasks? (2) How do we turn a team of experts into an expert team? The implications of these questions have been, first, to create realistic simulations that provide synthetic experience to accelerate the development of individual expertise. Second, these simulations must immerse teams in realistic, multi-player scenarios that build shared mental models, foster self-correction, enhance explicit coordination, and promote implicit communication. The challenge of embedded training is to implement scenario-based training with minimal external support. Intelligent tutoring systems is a possible approach to automating functions such as scenario generation, data collection and interpretation, diagnosis of performance deficiencies, and provision of feedback.

Endsley, Riley, and Strater viewed embedded training as an appropriate platform for enhancing high-level cognitive skills, including situation awareness (SA). They described a set of principled approaches for training the cognitive skills that underlie situation awareness (SA) and decision making that can be easily employed in future embedded training systems and can enhance their capabilities. These training approaches are (1) the SA Trainer, which employs systematic experiential-based training to build essential knowledge bases and higher-order cognitive skills; (2) the Virtual Environment Situation Awareness Review System (VESARS), which employs informed feedback on SA skills, team communications, and the accuracy and completeness of SA; and (3) the SA Virtual Instructor (SAVI), which builds critical SA skills by calibration of good and poor SA practices. The purpose of these tools is to develop and hone the needed SA skills for achieving high levels of performance.

5.2 Mind Mapping Exercises for Session 2

Dr. Andrews and Dr. Roessingh moderated the second round of mind mapping exercises, which focused on the following four questions:[1]

5.2.1 What are viable instructional strategies for EVS?

Although a wide variety of strategies may apply, EVS is best used in deployed (vice school house) situations. Different aspects of deployed training apply, such as reachback, cross-training, and refresher/sustainment training.

5.2.2 What categories of metrics can be use to manage EVS?

Again, the full range of metrics applies to EVS, from behavioural process measures (including psychophysiological indicators, such as eye movements) to tasks outcomes. However, the applicability of qualitative judgments (i.e., "style" points) may have limited applicability to the extent that they require additional experts outside of team/crewmembers.

5.2.3 How do you manage training sessions?

The principal question in management of EVS is determining the trainer. Can a leader or other team member also assume the role of trainer? Implementation of intelligent tutoring systems may help, at least in part. Also, an EVS must incorporate aspects of learning management systems (LMSs), such as trainee profiles. Such profiles would contain data related to experience, learning styles, and so forth. Prototypical LMSs are implemented in Sweden (Saab system) and Canada.

5.2.4 How do you envision tasks currently accomplished by "white cell" personnel?

In order to be implemented in EVSs, control functions normally performed by white cells must be automated to the extent possible. However, there is still a role for human white cell participants to provide instruction aimed at higher echelons or to provide reachback capabilities.

6.0 SESSION 3: HUMAN INTERACTION WITH EMBEDDED VIRTUAL SIMULATIONS

Dr. Thomas Alexander (DEU) and Dr. Sylvain Hourlier (FRA) moderated the third session, which focused on interface technology including sensors and controls. The effectiveness of such interfaces was discussed with respect to visual perception and decision making processes, such as target detection and identification.

6.1 Presentations in Session 3

Neuhöfer discussed a training system that embedded augmented reality for a dynamic industrial task requiring human-robot cooperation. The task was to remove undesired sand relics on cast metal parts using deep frozen CO_2 as residue-free detergent. In this task, the robot performs the heavyweight part handling whereas the human focuses on control, relics removal, and inspection. An immersive simulation was used to emulate this industrial environment and to test two control configurations. The augmented reality (AR) provided an optical

[1] A fifth question was able posed: How will you manage training in different modes (home station, in transit, in theatre)? None of the breakout groups was able to answer this question within the time allotted.

see-through display where the user sees the real control tool in his hand. This configuration was compared to a pure virtual reality (VR) mode where object visualization was artificial. Comparison of performance in execution times and shooting accuracy indicated no differences between AR and VR. NASA TLX surveys indicated relatively low mental and physical loads for both conditions, but there was a clear personal preference for the AR configuration, especially among women.

Embedded training has the capability to combine virtual or augmented input with real inputs from aircraft cockpits. Sandor et al. explored the possible deleterious effects of mismatches between synthetic inputs from embedded training systems and real inputs. Their first experiment examined the effects of visual structure in a virtually tilted environment. Results indicated that greater visual structure induced greater perceived distortion in tilt. Also, purely virtual controls induced greater distortion than did a combined virtual-kinetic control. The second experiment looked at the perceiver's frame of reference on the fusion of auditory with visual inputs. Previous research indicated that visual-auditory fusion is most affected by disparities in azimuth. Findings from the present research indicated that fusion was also affected by an integration of egocentric (bodily orientation) and allocentric (external visual) cues.

Dyer reported on the application of embedded training concepts in the Ground Soldier System (GSS) prototypes that are currently in development. The major components of these prototypes are a wearable computer and a global positioning system. The soldier receives input from this system via helmet-mounted or goggle-mounted display and manipulates the input via a soldier/system control unit. The GSS prototypes were examined for their capability to provide training in two areas. The first is individual instruction on a subset of soldier tasks, which were selected to meet both psychological criteria (e.g., hard to perform, infrequently performed) and warfighting criteria (e.g., lethality and survivability). The second area is collective training in a virtual environment. The current collective concept under examination was to integrate the GSS operational system in an external virtual environment. The conclusion of initial testing was that the potential for EVS training exists for GSSs, but its application is limited.

6.2 Mind mapping Exercises for Session 3

Dr. Alexander and Dr. Hourlier moderated the third mind mapping exercise, which addressed a single question: What are the limitations of embedded virtual simulation interface technology? It was generally noted that dismounted soldier systems, such as described by Dr. Dyer, present the most difficult implementation problems for EVS. More specific conclusions were discussed with respect to the following interface sensory modalities:

6.2.1 Vision

With respect to all modalities, visual displays are the best developed capabilities. Whereas visual cues are best when simulating day vision with the unaided eye, difficulties exist for night vision. Also, visual displays may be problematic for tasks that depend on depth cues and field of view.

6.2.2 Sound

Impressive Hollywood sound effects have been demonstrated. Localization effects are more difficult to simulate. Such problems and individual differences in sensitivity may be mitigated by the fact that many performers wear headphones in operational environment, which would also be employed in EVS.

6.2.3 Motion and Vibration

The most advanced work on motion cuing has been done in aircraft research. This research indicates that full motion simulation is expensive and its effectiveness is questionable. Lower cost motion simulations (haptic belts and vests) provide cheaper and potentially more effective alternative.

6.2.4 Chemical Senses

Devices exist to simulate certain odours, but problems pertain to dissipation in environment. Except for some medical tasks, it is also questionable whether there are many tasks that are cued or regulated by smells.

7.0 SESSION 4: LEARNING AND HUMAN EFFECTIVENESS IN EMBEDDED VIRTUAL SIMULATIONS

Ms. Claudy Koerhuis (NED) acted as facilitators for the fourth session, which focused on topics in student modeling, coaching strategies, and tutor perception.

7.1 Presentations in Session 4

Dr. Robert Sottilare (USA) made the argument that one of the ways that a human tutor adjusts one-on-one instruction is on the basis of the perceived affective state of the learner. Adjustments to instructional strategy can alter those moods, which in turn impacts the effectiveness of learning. Some initial research findings indicate that there are computer algorithms for detecting affective states that could be applied to intelligence tutoring systems. To be implemented in embedded training such algorithms should be accurate, portable, affordable, passive, and effective. Given deficiencies in these areas, Sottilare recommended three areas for further research: sensors, predictive models, and building trust.

Jensen, Mosley, Sanders, and Sims explored the efficacy of feedback methods for intelligent embedded tutoring systems. Their paper reviewed two case studies of embedded training designed to deliver feedback with little or no instructor involvement. The first was a man-wearable trainer for dismounted operations, which provided feedback on the individual soldier position and tracking behaviour, and presented semi-automated force (SAF) entities to simulate other soldiers. Feedback from soldiers indicated that most effective training was provided for simple procedural tasks (maintain muzzle awareness and maintain sectors of fire), whereas the least effective training were those requiring coordination with SAF entities (team movement and room clearing. The second case study involved a robotic vehicle control station trainer, and compared two feedback conditions: Immediate Directive Feedback (IDF) provided by the intelligent tutoring system versus human-facilitated after action reviews (AAR)s using open-ended, content neutral prompts. The relative effectiveness of these two approaches depended on type of tasks: Results indicated decreased errors for IDF condition on procedural tasks, but increased retention for AARs on conceptual tasks.

Bell and Short noted that communication and team coordination have been overlooked in embedded simulation because complex and highly verbal interactions are difficult to simulate without human role players. The capability to train communication and coordination was seen as particularly relevant to deployed NATO units. To address this issue, the authors employed a cognitive modelling tool that encapsulates human expertise and behaviour in synthetic agents. These agents incorporate speech recognition, conversation management, and speech generation capabilities. These tools were implemented in synthetic environments for training two different domains. One domain was air-ground communications task between pilot and the tower controller wherein the role of the controller, as well as the instructor pilot, was simulated. Use of this system

was positively correlated with reduced time to achieve a rating of "good" on flown sorties. The other domain was mission planning and rehearsal for close air support (CAS). The same system was embedded in the Combined Arms Gateway Environment (CAGE) which is design to plan, rehearse, and conduct missions. Within a CAS scenario, synthetic agents were used to role play the Joint Terminal Attack Controller (JTAC) and interact with a pilot user. An operational evaluation of this system showed that voluntary use was positively correlated with training gains in situation awareness, communications, and in-flight checks.

To minimize the need for instructional staff or infrastructure, Heuvelink, van den Bosch, van Doesburg, and Harbers advocated the use intelligent agents that emulate the actions of fellow team members, opponents, and instructors. The thesis of their paper was that there is also a need for a director agent (DA) to diagnose the trainee's task performance, instruct agents to perform certain behaviour, and steer the simulation. The goal of the DA's actions is to tailor the training scenario so that it is a bit more difficult than the trainee's current level of performance. This concept was tested on a single-player table-top system that simulates fire fighting on board a Royal Netherlands Navy frigate. In this system, the trainee assumes the role of the commanding officer, the Officer of the Watch (OW). To perform his tasks, the OW communicates with four other officers, all of which are simulated by intelligent agents developed using the Belief-Desire-Intention (BDI) framework. The DA is also modelled as a BDI agent but operates "behind the scenes" based on information from the virtual simulation and the trainee. The DA affects training through control of the simulated environment and/or the behaviour of the other agents. The authors concluded that their project demonstrated that the DA provided value added for embedded virtual simulations.

7.2 Mind mapping Exercises for Session 4

Dr. Robert Sottilare (USA) and Ms. Claudy Koehuis (NED) acted as facilitators for the fourth mind mapping exercise, which concerned issues related to learning in EVS. The discussion was centred on the following two issues:

7.2.1 What are the factors that enable or limit learning in EVS training?

Some of the key factors include

- availability of instructors and role players
- noises and other distractions inherent in the operational environment
- whether trainees possess appropriate metacognitive/learning strategies to support training
- ability of training strategy to adapt to individual learning needs
- ability of training strategy to adapt to individual stress levels or affective states
- competition of training with operational requirements.

7.2.2 How is feedback provided to trainees during embedded training?

8.0 CONCLUSIONS

Some of the most mature applications of EVS have been in command and control (C2) domains. Examples are command centres for missile defence and shipboard AEGIS systems. The advantages of such domains are that EVS systems are not subject to severe weight and space limitations, and that computational resources are relatively plentiful. Also, typical C2 displays do not require high-fidelity visual systems to create realistic virtual environments.

On the other hand, developments in visual simulation have led to significant advances in EVS for ground and air combat vehicle platforms. These advances are typified in the development of the FCS and the F-35, both of which explicitly required embedded training to be included in their overall design concepts. Both systems have been depicted as archetypes for the application of embedded training systems in new combat vehicles.

Training for dismounted warfighters remains perhaps the most difficult application for embedded training. This is partly due to the severity of size and weight restrictions for man-carried systems. Also, simulation and/or augmentation of unaided vision remain significant challenges. Although prototype embedded training systems for dismounted warfighters exist, limitations such as these have seriously restricted their capabilities.

A fundamental requirement for EVS systems intended for deployed personnel and crews is they minimize the need for external instructional support. The emerging technologies of intelligent agents and intelligent tutoring systems provide the capability to embed instructional support into the training system. However, the technologies are relatively immature and progress has been limited to demonstration projects.

Although the effectiveness of EVS was documented, conference members expressed disappointment that the technology has not been more generally accepted by system and training developers. One inhibiting factor that was identified in mind mapping exercises was the lack of NATO guidance on development of EVS systems. It was suggested that the present NATO group continue to monitor the evolution of EVS technology to develop appropriate guidance and policy.

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